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(54) **CARRIER FREQUENCY OFFSET CALIBRATION METHOD**

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H04L 25/02 (2006.01)

(52) **U.S. Cl.**
CPC ***H04L 27/2657*** (2013.01); ***H04L 25/0204*** (2013.01)

(58) **Field of Classification Search**
CPC H04L 27/2655; H04L 27/2657; H04L 27/2659; H04L 27/266; H04L 2027/0026; H04L 2027/0028; H04L 2027/003; H04L 2027/0032; H04L 2027/0034; H04L 2027/0036
USPC 375/259, 260, 285, 316, 344, 346, 348
See application file for complete search history.

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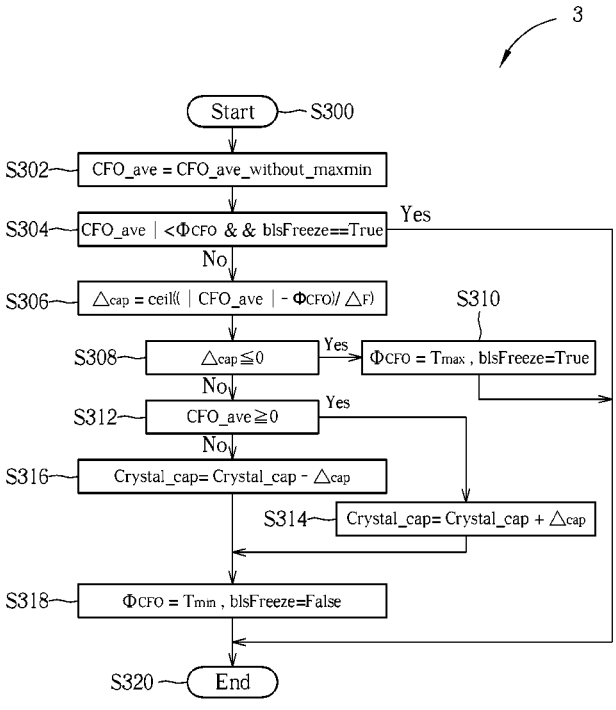
(57) **ABSTRACT**

A carrier frequency offset (CFO) calibration method for calibrating a CFO of a receiver is proposed. The CFO calibration method includes: receiving at least one CFO estimation value generated by digital CFO estimation; generating a CFO adjustment value according to the at least one CFO estimation value; and adjusting an oscillation frequency of an oscillator of the receiver according to the CFO adjustment value.

18 Claims, 4 Drawing Sheets



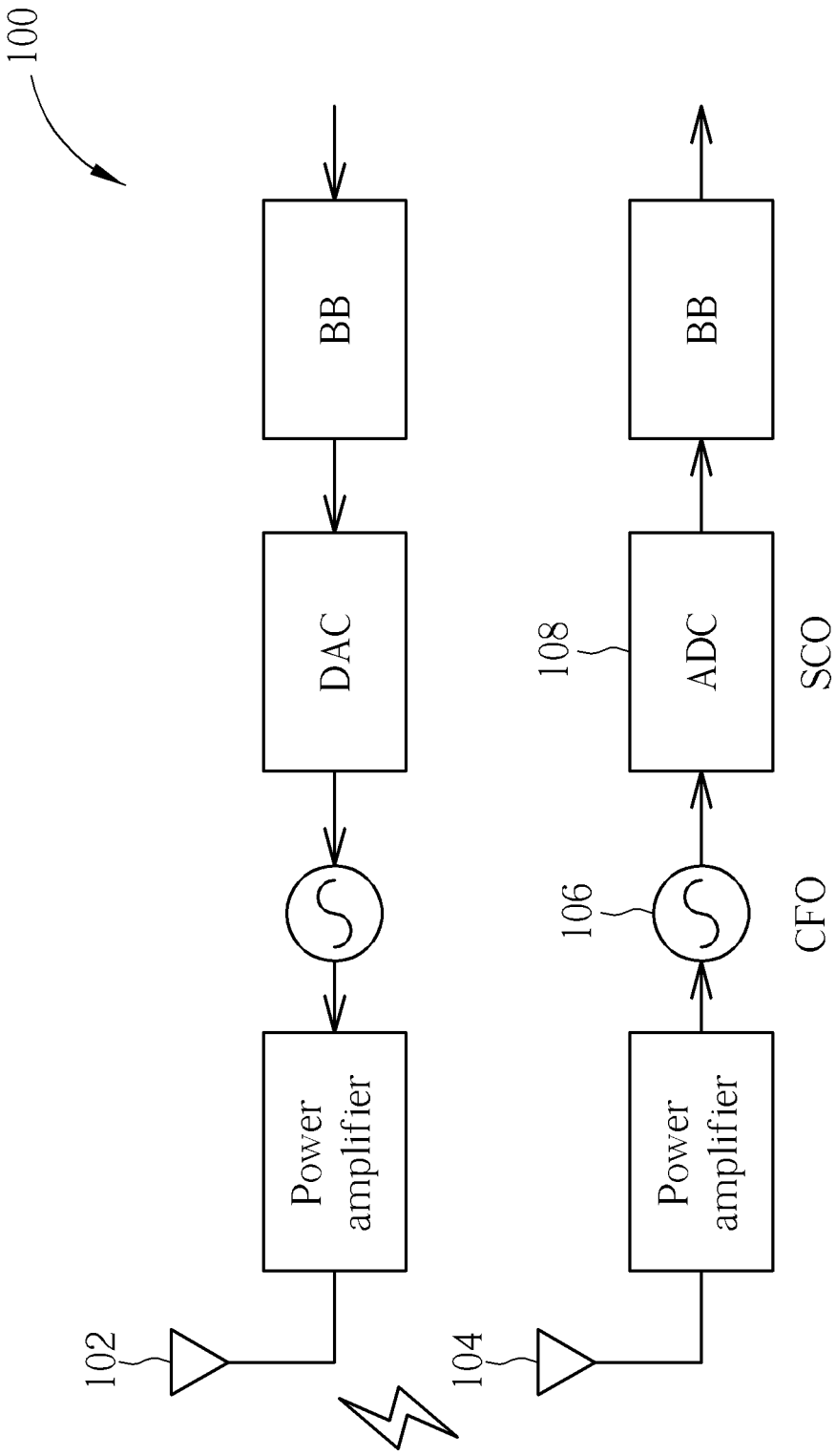


FIG. 1 PRIOR ART

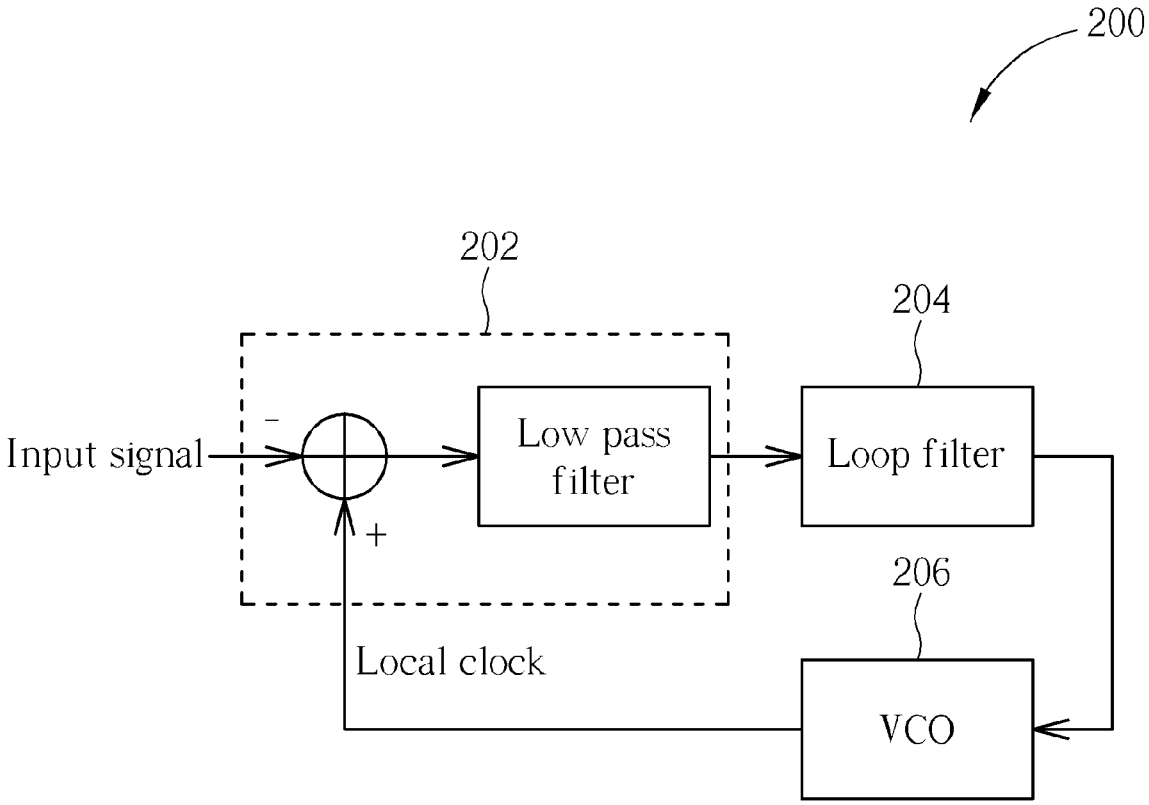


FIG. 2 PRIOR ART

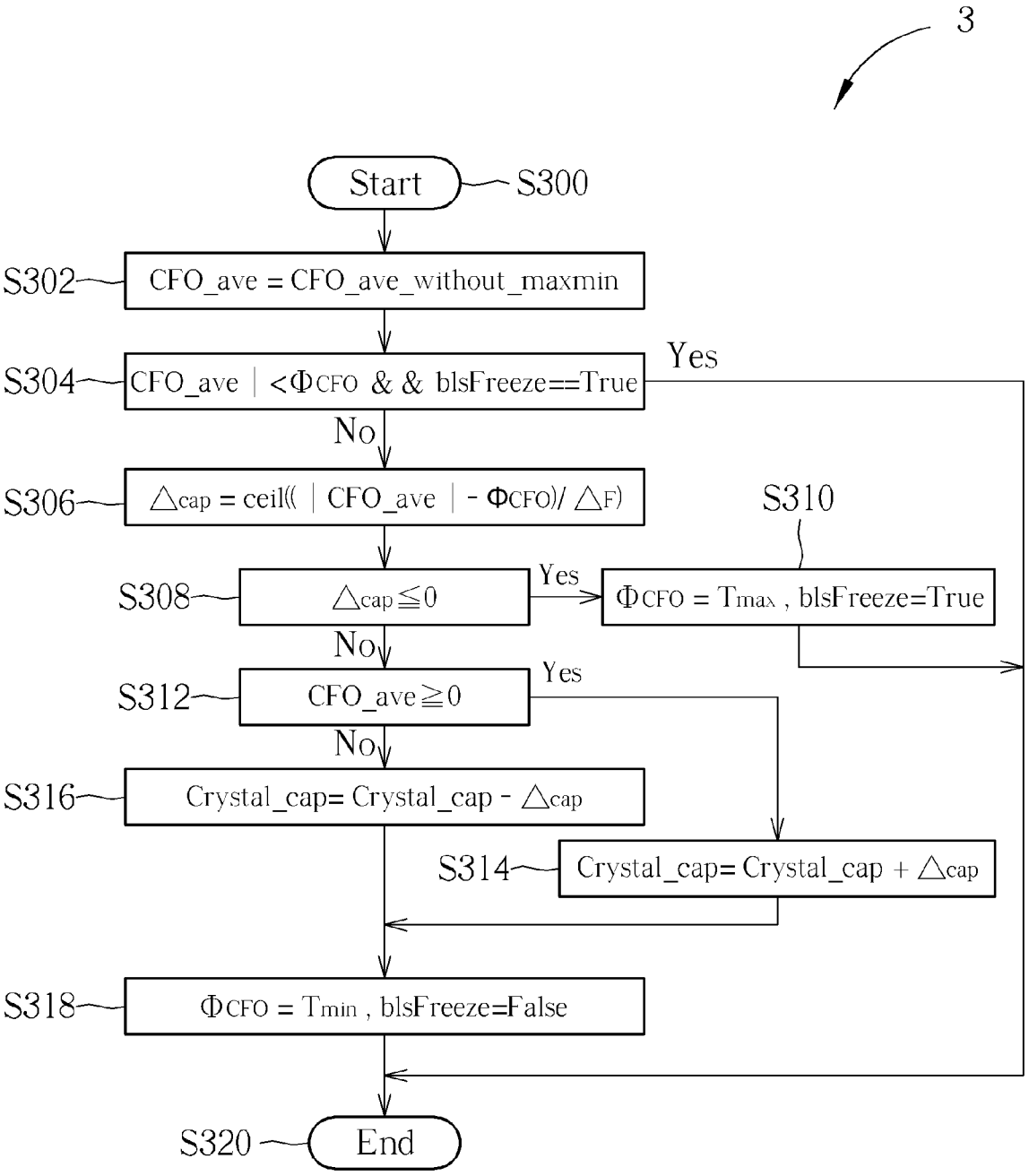

3
Start
S300
S302
CFO_ave = CFO_ave_without_maxmin
S304
CFO_ave | <ΦCFO && blsFreeze==True
Yes
No
S306
△cap = ceil((| CFO_ave | - ΦCFO)/ △F)
S310
S308
△cap≦0
Yes
ΦCFO = Tmax , blsFreeze=True
No
S312
CFO_ave≧0
Yes
No
S316
Crystal_cap= Crystal_cap - △cap
S314
Crystal_cap= Crystal_cap + △cap
S318
ΦCFO = Tmin , blsFreeze=False
S320
End

FIG. 3

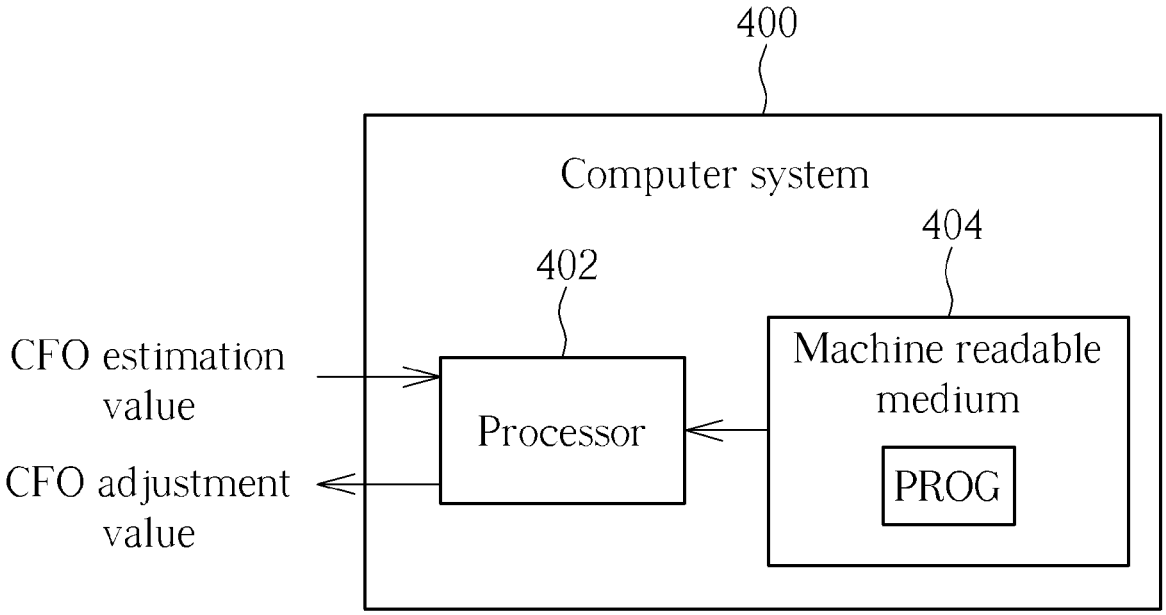

400
Computer system
404
402
CFO estimation value
Processor
Machine readable medium
PROG
CFO adjustment value

FIG. 4

CARRIER FREQUENCY OFFSET CALIBRATION METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

The disclosed embodiments of the present invention relate to a carrier frequency offset (CFO) calibration method, and more particularly, to a CFO calibration method applied to an Orthogonal Frequency Division Multiplexing (OFDM) receiver.

2. Description of the Prior Art

In general, in an Orthogonal Frequency Division Multiplexing (OFDM) communication system such as an OFDM communication system **100** shown in FIG. **1**, since there is a frequency difference between oscillators (not shown) in a transmission terminal **102** and a receiving terminal **104**, causing to the carrier frequency offset (CFO) problem in frequency domain and sample clock offset (SCO) problem in time domain in receiving terminal **104**.

The CFO and the SCO are main reasons of damaging the system carrier orthogonality. Under conditions of no calibration or lack of calibration, it will cause a severe Inter Carrier Interference (ICI). Thus, it is important about how to perform the CFO calibration in the OFDM receiver. A conventional method of solving the above problem is using a phase lock loop (PLL) to perform the CFO calibration. As shown in FIG. **2**, a PLL **200** uses a phase detector (PD) **202** to find out a phase difference between an input signal and a local clock first, and then calculates a frequency difference by a math calculation. After passing through a loop filter **204**, an output clock of a voltage-controlled oscillator (VCO) **206** will be adjusted according to the frequency difference in order to change the frequency of the local oscillator, to perform the CFO calibration or tracking. However, the PLL is usually realized in an analog way, and it is not only difficult in design, but also easy to be affected by process floating, and it requires more chip area.

In addition, there is another conventional method which can be realized by digital signal processing only. Specifically, this conventional method does not use the analog circuit or radio frequency (RF) circuit for the calibration, but simply performs the CFO estimation by a base band (BB) digital circuit, and performs a CFO compensation by signal processing to eliminate influences of the carrier interference. In general, besides the estimation and the compensation, it is practical to perform CFO tracking & SCO tracking based on a pilot signal in the signals, so as to reduce the influence caused by problems of inaccurate estimations and compensations. However, although it is easier to use the BB digital circuit to perform the CFO calibration, but the following problems might occur. First, a DC notch filter might be affected by the CFO and signals near DC are filtered and can not be restored. Second, when the CFO effect is serious, the CFO estimation capability of the digital circuit might reduce greatly due to preamble symbol detection errors or decode errors.

Thus, there is immediate requirement of an innovative CFO calibration method to reduce cost and error rate.

SUMMARY OF THE INVENTION

It is therefore one of the objectives of the present invention to provide a carrier frequency offset (CFO) calibration method applied to an Orthogonal Frequency Division Multiplexing (OFDM) receiver, so as to solve the problem of harmonic oscillation.

In accordance with an embodiment of the present invention, an exemplary CFO calibration method is disclosed. The exemplary CFO calibration method comprises: receiving at least one CFO estimation value generated by a digital CFO estimation; generating a CFO adjustment value according to the at least one CFO estimation value; and adjusting an oscillation frequency of an oscillator of the receiver according to the CFO adjustment value.

In accordance with an embodiment of the present invention, an exemplary machine readable medium is disclosed. The exemplary machine readable medium stores a program code, wherein when the program code is executed by a processor, the program code makes the processor execute following steps to calibrate carrier frequency offset (CFO) of a receiver: receiving at least one CFO estimation value generated by a digital CFO estimation; generating a CFO adjustment value according to the at least one CFO estimation value; and adjusting an oscillation frequency of an oscillator of the receiver according to the CFO adjustment value.

Compared to the prior art, the CFO calibration method applied to an Orthogonal Frequency Division Multiplexing (OFDM) receiver disclosed by the present invention can obviously reduce complexity of an analog circuit and reduce CFO effect of source signal (RF signal) causing preamble process performance degraded.

These and other objectives of the present invention will no doubt become obvious to those of ordinary skill in the art after reading the following detailed description of the preferred embodiment that is illustrated in the various figures and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified diagram of a conventional Orthogonal Frequency Division Multiplexing (OFDM) communication system.

FIG. **2** is a simplified diagram of a conventional phase lock loop (PLL).

FIG. **3** is a flowchart showing a CFO calibration method in accordance with an exemplary embodiment of the present invention

FIG. **4** is a simplified diagram of a machine readable medium applied to the CFO calibration in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

Certain terms are used throughout the description and following claims to refer to particular components. As one skilled in the art will appreciate, manufacturers may refer to a component by different names. This document does not intend to distinguish between components that differ in name but not function. In the following description and in the claims, the terms "include" and "comprise" are used in an open-ended fashion, and thus should be interpreted to mean "include, but not limited to . . . ". Also, the term "couple" is intended to mean either an indirect or direct electrical connection. Accordingly, if one device is coupled to another device, that connection may be through a direct electrical connection, or through an indirect electrical connection vian Other devices and connections.

The present invention generating a calibrate carrier frequency offset (CFO) adjustment value according to a CFO estimation value generated by a digital CFO calculating circuit of conventional receiver based on a digital CFO estimation, wherein the digital CFO estimation can be a conventional method. For example, the feature of the digital CFO

estimation is not utilizing an analog circuit or a radio frequency (RF) circuit to perform the estimation, but simply perform the CFO estimation by a base band (BB) circuit, wherein the estimation theory can be defined by a system spec or realized by a designer using another algorithm. The feature of the present invention is processing the CFO adjustment value generated by the digital CFO estimation, and further making the processed signal feedback to the analog circuit to adjust a source oscillator frequency of a clock signal in a front end of the receiver, but not only performing a compensation at the digital BB circuit in a back end of the receiver. The detail illustration is in the following paragraphs.

Please refer to FIG. **3**. FIG. **3** is a flowchart showing a CFO calibration method **3** in accordance with an exemplary embodiment of the present invention, wherein the CFO calibration method can be applied to an Orthogonal Frequency Division Multiplexing (OFDM) receiver. The CFO calibration method **3** calculates a CFO adjustment value CFO (i.e. a capacitance adjustment value Δ_{cap} of an oscillator) according to a CFO estimation value CFO_est generated by a digital CFO calculating circuit in the OFDM receiver and a frequency offset value Δ_F and a frequency offset direction corresponding to unit capacitance of a control capacitance Crystal_cap of the oscillator in the OFDM receiver. In step **S302**, extreme values in all CFO estimation values CFO_est during a specific time interval T can be omitted in order to reduce over adjusting conditions and extreme conditions, and calculate a mean value of the rest of CFO estimation values CFO_est to obtain a mean CFO estimation value CFO_ave_without_maxmin without extreme values. The mean CFO estimation value CFO_ave_without_maxmin is viewed as a mean CFO estimation value CFO_ave during the specific time interval T. Please note that since the oscillator frequency in a transmission terminal than the oscillator frequency in a receiving terminal might be faster or slower, the mean CFO estimation value CFO_ave might be a positive value or a negative value.

Next, in step **S304**, determining whether an absolute value of the mean CFO estimation value |CFO_ave| is smaller than a threshold value Φ_{CFO} and a flag blsFreeze is equal to True is performed. If yes, then go to step **S320**. If no, then go to step **S306** and calculate a capacitance adjustment value Δ_{cap}=ceil((|CFO_ave|−Φ_{CFO})/Δ_F), wherein ceil((CFO_ave|−Φ_{CFO})/Δ_F) is a roundup calculation of (|CFO_ave|−Φ_{CFO})/Δ_F. Next, in step **S308**, determining whether Δ_{cap} is smaller than or equal to 0 is performed. If yes, then go to step **S310** and determine the threshold value Φ_{CFO} is a first threshold value T_{max} and set the flag blsFreeze to be True. If Δ_{cap} is determined to be not smaller than or equal to 0 in the step **S308**, then go to step **S312**.

In step **S312**, determining whether the mean CFO estimation value CFO_ave is greater than or equal to 0 is performed. If yes, then go to step **S314** and set the control capacitance of the oscillator in the OFDM receiver to be Crystal_cap=Crystal_cap+Δ_{cap}, and then go to step **S318**. Otherwise, if the mean CFO estimation value CFO_ave is not greater than or equal to 0, then go to step **S316** and set the control capacitance of the oscillator in the OFDM receiver to be Crystal_cap=Crystal_cap−Δ_{cap}, and then go to step **S318**. In step **S318**, determine the threshold value Φ_{CFO} is a second threshold value T_{min} and set the flag blsFreeze to be False is performed.

After the absolute value of the mean CFO estimation value |CFO_ave| is over the first threshold value T_{max}, the CFO adjustment value is constantly updated according to a mean CFO estimation value generated during a subsequent specific time interval to calibrate the oscillator of the OFDM receiver, until the mean CFO estimation value generated during the subsequent specific time interval is lower than the second threshold value T_{min}. That is, the hysteresis comparison theory is utilized for eliminating instability of the mean CFO estimation value CFO_ave in a range between the second threshold value T_{min} and the first threshold value T_{max}.

In addition, some specific steps of the flowchart showing a CFO calibration method **3** in FIG. **3** can have changes according to different requirements. For example, it is practical to determine whether a difference ΔCFO_ave of the mean CFO estimation value CFO_ave during a specific time interval T_1 and a mean CFO estimation value CFO_ave_{-1} during a previous specific time interval T_{-1} is over an abnormal threshold value. That is, if the mean CFO estimation value CFO_ave suddenly has a very big change compared with the mean CFO estimation value CFO_ave_{-1}, then the mean CFO estimation value CFO_ave is an accidental abnormal value which is caused by noises or some abnormal conditions, and thus the accidental abnormal value is not adopted to generate the capacitance adjustment value Δ_{cap} to avoid wrong calibration. In addition, for example, if ΔCFO_ave is over a threshold value Φ_{CFO_diff}, then terminate the CFO calibration of the specific time interval T_1. However, if this condition constantly happens, for example, a difference ΔCFO_ave_{-1} between the mean CFO estimation value CFO_ave_{-1} calculated in the previous specific time interval T_{-1} and the mean CFO estimation value CFO_ave_{-2} calculated in another previous specific time interval T_{-2} is over the threshold value Φ_{CFO_diff}, and ΔCFO_ave is also over the threshold value Φ_{CFO_diff}, then it is possible that this drastic change is not an accidental abnormal condition, but is a CFO requires the calibration. The mean CFO estimation value CFO_ave should be viewed as a normal one and adopted to generate the capacitance adjustment value Δ_{cap} to adjust the oscillator in the receiving terminal.

Please refer to FIG. **4**. FIG. **4** is a simplified diagram of a machine readable medium applied to the CFO calibration in accordance with an embodiment of the present invention. A computer system **400** comprises a processor **402** and a machine readable medium **404**. For example, the computer system **400** can be a personal computer (PC) and the machine readable medium **404** can be any kind of storage device with data storing function in the PC, such as volatile memory, non-volatile memory, hard disk, optical disk, etc. In this embodiment, the machine readable medium **404** stores a program code PROG. When the program code PROG is loaded and executed by the processor **402**, the program code PROG will make the processor receive at least one CFO estimation value generated by a digital CFO estimation to generate a CFO adjustment value, and adjust an oscillation frequency of an oscillator of the receiver according to the CFO adjustment value. That is, the program code PROG makes the processor **402** executes the CFO calibration method disclosed by the present invention (i.e. the steps **S300**-**S324** in FIG. **3**). Since those of average skill in this art can understand the timing analysis operation of the processor **402** executing the program code PROG by referring to the above timing analysis method, further explanation of the details and operations are omitted herein for the sake of brevity.

The CFO calibration method applied to the OFDM receiver disclosed by the present invention can be realized by a BB digital circuit. It also can be realized by a software or a firmware, and makes the calculation result written into the register of the BB digital circuit or feedback to an analog circuit to control frequency of the oscillator, in order to achieve the purpose of CFO calibration. Compared to the prior art, the present invention can obviously reduce com-

plexity of an analog circuit and reduce CFO effect of source signal (RF signal) causing preamble process performance degraded.

Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

What is claimed is:

1. A carrier frequency offset (CFO) calibration method for calibrating a CFO of a receiver, the CFO calibration method comprising:

receiving at least one CFO estimation value generated by a digital CFO estimation;

calculating a mean CFO estimation value according to a plurality of CFO estimation values generated by the digital CFO estimation during a specific time interval;

determining whether the mean CFO estimation value is over a threshold value;

when the mean CFO estimation value is over the threshold value, generating a CFO adjustment value according to the mean CFO estimation value; and

adjusting an oscillation frequency of an oscillator of the receiver according to the CFO adjustment value;

wherein the step of determining whether the mean CFO estimation value is over the threshold value further comprises: after the mean CFO estimation value is over the threshold value, constantly updating the CFO adjustment value according to a mean CFO estimation value generated during a subsequent specific time interval, until the mean CFO estimation value generated during the subsequent specific time interval is lower than another threshold value.

2. The CFO calibration method of claim **1**, wherein the receiver is an Orthogonal Frequency Division Multiplexing (OFDM) receiver.

3. The CFO calibration method of claim **1**, wherein the step of generating the CFO adjustment value according to the at least one CFO estimation value comprises:

calculating the CFO adjustment value according to the at least one CFO estimation value and a frequency offset value and a frequency offset direction corresponding to unit capacitance of a control capacitance of the oscillator.

4. The CFO calibration method of claim **3**, wherein the step of adjusting the oscillation frequency of the oscillator of the receiver according to the CFO adjustment value comprises:

adjusting control capacitance of the oscillator according to the CFO adjustment value.

5. The CFO calibration method of claim **1**, wherein the step of calculating the mean CFO estimation value according to the CFO estimation values generated by the digital CFO estimation during the specific time interval comprises:

selecting a part of CFO estimation values from the CFO estimation values, wherein the part of CFO estimation values do not comprise at least of a maximum value and a minimum value of the CFO estimation values; and

calculating the mean CFO estimation value according to the part of CFO estimation values.

6. The CFO calibration method of claim **1**, wherein the step of generating the CFO adjustment value according to the at least one CFO estimation value comprises:

calculating a mean CFO estimation value of each time interval according to a plurality of CFO estimation values generated by the digital CFO estimation during the each time interval of a current time interval and a plurality of previous time intervals, to obtain a plurality of mean CFO estimation values corresponding to the current time interval and the previous time intervals, respectively;

determining whether the mean CFO estimation value is over a threshold value; and

when the mean CFO estimation value is over the threshold value, generating the CFO adjustment value according to the mean CFO estimation value.

7. A non-transitory machine readable medium for storing a program code, wherein when the program code is executed by a processor, the program code makes the processor execute following steps to calibrate carrier frequency offset (CFO) of a receiver:

receiving at least one CFO estimation value generated by a digital CFO estimation;

determining whether the mean CFO estimation value is over a threshold value;

when the mean CFO estimation value is over the threshold value, generating a CFO adjustment value according to the mean CFO estimation value; and adjusting an oscillation frequency of an oscillator of the receiver according to the CFO adjustment value;

wherein the step of determining whether the mean CFO estimation value is over the threshold value further comprises:

after the mean CFO estimation value is over the threshold value, constantly updating the CFO adjustment value according to a mean CFO estimation value generated during a subsequent specific time interval, until the mean CFO estimation value generated during the subsequent specific time interval is lower than another threshold value.

8. The non-transitory machine readable medium of claim **7**, wherein the receiver is an Orthogonal Frequency Division Multiplexing (OFDM) receiver.

9. The non-transitory machine readable medium of claim **7**, wherein the step of generating the CFO adjustment value according to the at least one CFO estimation value comprises:

calculating the CFO adjustment value according to the at least one CFO estimation value and a frequency offset value and a frequency offset direction corresponding to unit capacitance of a control capacitance of the oscillator.

10. The non-transitory machine readable medium of claim **9**, wherein the step of adjusting the oscillation frequency of the oscillator of the receiver according to the CFO adjustment value comprises:

adjusting control capacitance of the oscillator according to the CFO adjustment value.

11. The non-transitory machine readable medium of claim **7**, wherein the step of generating the CFO adjustment value according to the at least one CFO estimation value comprises:

calculating a mean CFO estimation value of each time interval according to a plurality of CFO estimation values generated by the digital CFO estimation during the each time interval of a current time interval and a plurality of previous time intervals, to obtain a plurality of mean CFO estimation values corresponding to the current time interval and the previous time intervals, respectively;

determining whether the mean CFO estimation value is over a threshold value; and

when the mean CFO estimation value is over the threshold value, generating the CFO adjustment value according to the mean CFO estimation value.

12. The non-transitory machine readable medium of claim **7**, wherein the step of determining the mean CFO estimation

value according to the CFO estimation values generated by the digital CFO estimation during the specific time interval comprises:

selecting a part of CFO estimation values from the CFO estimation values, wherein the part of CFO estimation values do not comprise at least of a maximum value and a minimum value of the CFO estimation values; and

calculating the mean CFO estimation value according to the part of CFO estimation values.

13. A carrier frequency offset (CFO) calibration method for calibrating a CFO of a receiver, the CFO calibration method comprising:

receiving at least one CFO estimation value generated by a digital CFO estimation;

calculating a mean CFO estimation value of each time interval according to a plurality of CFO estimation values generated by the digital CFO estimation during the each time interval of a current time interval and a plurality of previous time intervals, to obtain a plurality of mean CFO estimation values corresponding to the current time interval and the previous time intervals, respectively;

determining whether differences between mean CFO estimation values corresponding to each two successive time intervals in the current time interval and the previous time intervals respectively are over a threshold value;

when all of the differences between the mean CFO estimation values corresponding to each two successive time intervals in the current time interval and the previous time intervals respectively are over the threshold value, generating a CFO adjustment value according to the mean CFO estimation value of the current time interval; and

adjusting an oscillation frequency of an oscillator of the receiver according to the CFO adjustment value.

14. The CFO calibration method of claim **13**, wherein the receiver is an Orthogonal Frequency Division Multiplexing (OFDM) receiver.

15. The CFO calibration method of claim **13**, wherein the step of generating the CFO adjustment value according to the at least one CFO estimation value comprises:

calculating the CFO adjustment value according to the at least one CFO estimation value and a frequency offset value and a frequency offset direction corresponding to unit capacitance of a control capacitance of the oscillator.

16. The CFO calibration method of claim **15**, wherein the step of adjusting the oscillation frequency of the oscillator of the receiver according to the CFO adjustment value comprises:

adjusting control capacitance of the oscillator according to the CFO adjustment value.

17. The CFO calibration method of claim **13**, wherein the step of generating the CFO adjustment value according to the at least one CFO estimation value comprises:

calculating a mean CFO estimation value according to a plurality of CFO estimation values generated by the digital CFO estimation during a specific time interval;

determining whether the mean CFO estimation value is over a threshold value; and

when the mean CFO estimation value is over the threshold value, generating the CFO adjustment value according to the mean CFO estimation value.

18. The CFO calibration method of claim **17**, wherein the step of calculating the mean CFO estimation value according to the CFO estimation values generated by the digital CFO estimation during the specific time interval comprises:

selecting a part of CFO estimation values from the CFO estimation values, wherein the part of CFO estimation values do not comprise at least of a maximum value and a minimum value of the CFO estimation values; and

calculating the mean CFO estimation value according to the part of CFO estimation values.

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